

## University of Groningen

### Emerging perception

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*Document Version*

Publisher's PDF, also known as Version of record

*Publication date:*

2017

[Link to publication in University of Groningen/UMCG research database](#)

*Citation for published version (APA):*

Nordhjem, B. (2017). *Emerging perception: Tracking the process of visual object recognition*. [Thesis fully internal (DIV), University of Groningen]. Rijksuniversiteit Groningen.

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# Thesis summary

Human observers have the remarkable ability to make sense of complex sensory information and recognize objects seemingly instantaneously. Yet, object recognition relies on multiple processes unfolding over time. Within this thesis, I addressed the following question:

**What changes occur in an observer's visual system during the transition from the initial viewing to the recognition of an object?**

I described a number of studies in which I analyzed gaze behavior and brain activity during object recognition. In vision science, object recognition is often studied with overly simplified stimuli, such as objects shown on a uniform gray background. Nevertheless, human observers are able to group sparse information into whole objects and recognize ambiguous stimuli. In my experiments, I made use of a range of stimuli that challenge the visual system, such as objects gradually revealed from noise, bistable images, and emerging images. Using images that are not recognized immediately or can be recognized in several ways made it possible to capture the process of recognition as it happens.

## **Emerging images reveal fast detection yet slow recognition**

I used a new kind of stimulus, emerging images, akin to the famous Gestalt image of a Dalmatian on a spotted background. I studied eye movements over time while participants explored and recognized these images. Participants detected the location of the emerging object within hundreds of milliseconds, but they typically needed several seconds before indicating recognition. Eye movements transitioned from scanning to close inspection of the object around the moment of recognition. Two saliency models failed to predict the eye movements made by observers and to detect the object locations. Curiously, contemporary computer vision algorithms cannot recognize the emerging images either. Hence, emerging images can be a useful tool to study human object recognition and distinguish the perceptual and cognitive processes.

## **Object recognition relies on distributed processing**

The mechanisms underlying human object recognition are traditionally thought to take place in a feedforward manner, where simple features, such as orientation and contrast, are processed in the early visual cortex. However, the role of feedback in early visual areas has still not been sufficiently investigated. In an experiment, I found interactions between the primary visual cortex (V1) and higher-order visual regions, as well as lateral interaction between higher-order areas, during the recognition of images that were gradually revealed from noise. In a second imaging study using bistable images that switched between perceptual states during viewing, bistable perception was associated with activity within attentional circuits, and specific stimulus types were associated with processing in higher-order sensory areas. Taken together, these results support the notion that object recognition relies on distributed cortical processing.

## Cortical priority mapped in V1

Navigating the visual environment requires the integration of retinal stimulation and behavioral goals, which together can be described as priority. By evaluating the responses of V1 during an object recognition task, I tested the hypotheses that V1 may represent priority. Participants viewed emerging images, while cortical responses before and after recognition were recorded using fMRI. Following recognition, the V1 responses were modulated following recognition. Given that the images remained identical, I speculate that V1 activity reflects priority rather and not only retinal stimulation or visual saliency.

## Method development and applications

I also contributed to the effort to understand visual recognition as a dynamic temporal process happening over time by developing a new toolbox, EyeCourses, to study and compare eye tracking data as time courses. Furthermore, I mapped priority in the visual cortex in a novel way by combining population receptive field mapping with BOLD responses to create spatially detailed maps of differential cortical activity before and after object recognition. The stimuli and methods in this thesis could be translated into a set of tools that could be used for assessing viewing behavior, recognition performance, and cortical priority in clinical studies.

## From algorithms to art

In addition to my scientific work, in this thesis I also described my interdisciplinary art installation *(e)motion*. This work was inspired by cognitive neuroscience, and used computer vision algorithms to track the facial movements of participants interacting with the installation. *(e)motion* is an example of scientific methods applied in an artistic way to create novel experiences.

## Conclusions

My studies using gaze behavior and V1 activity showed that, as part of the object recognition process, object features are prioritized over other parts of a scene. Such prioritization can be deduced from changes in eye movement behavior, as well as from the selective enhancement and suppression of V1 activity during the transition from initial viewing to the recognition of an object. Moreover, I found that changes in perception are accompanied by activity in cortical attention circuits, and that early and later sensory areas modulate their exchange of information during object recognition. From this, I conclude that visual object recognition does not occur at once and in a single cortical area, but is a constructive and distributed cortical process.